

THE ORGANIC RANKINE CYCLE – A TECHNOLOGY FOR POWER PRODUCTION FROM LOW TEMPERATURE HEAT

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The Organic Rankine Cycle (ORC) is a favourable process for power production from low to medium temperature heat sources. The working principle of an ORC is similar to the most widely used process for power generation, the Clausius Rankine Cycle. The main difference is the use of organic substances, like silicone oils, fluorocarbons or hydrocarbons instead of water / steam as working fluid. The boiling pressure of these substances at low temperatures is higher compared with water.

A schematic representation of such a system is shown in Fig. 1. The evaporator (1) is heated by an external heat source like a biomass boiler, geothermal, solar thermal or waste heat. The organic working fluid is evaporated and then expanded in the turbine (2) which mostly is connected with a generator. In the Project RO-Solar-Rankine it is directly coupled with a high pressure pump (3). Due to the thermodynamic characteristic for some organic fluids the exhaust steam is still superheated. This allows using the sensible heat of the superheated steam for preheating the working fluid in the recuperator (6). The steam is then condensed in the condenser (4), which can be linked with a district heating network for combined heat and power production. After the condensation, the liquid working fluid is pumped back with the feed pump (5).

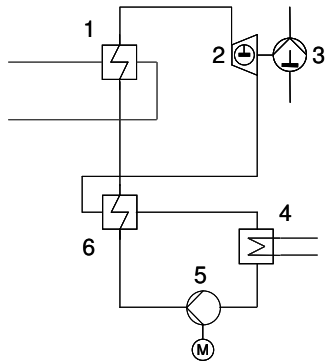


Fig. 1: Schematic Representation of ORC

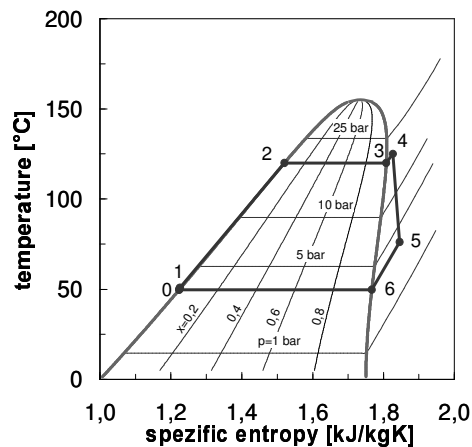


Fig. 2: T-s-Diagram for organic fluid

The temperature-entropy diagram of an organic fluid is shown in Fig. 2. The course of the process is as follows: the fluid is compressed by the feed pump (0-1), then preheated (1-2), evaporated (2-3) and superheated (3-4). The superheated steam is expanded (4-5), desuperheated (5-6) and condensed (6-0). It can be clearly seen, that the temperature of the exhaust steam (5) is higher than the liquid working fluid leaving the feed pump. Due to this fact, a part of the sensible heat of the exhaust steam is used for preheating the liquid fluid. Furthermore the enthalpy difference over the turbine is less compared with water. This leads to higher mass flows, which lowers the percentage inner leakage losses of the turbine.

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Due to this favourable features the ORC is at the moment the state-of-the-art solution for electricity production from solid biomass in a power range of 400 – 1500 kW. The manufacturer Turboden (Italy) has already sold more than 60 ORCs mostly used for combined heat and power production. The temperature of the heat source is around 300 °C, the working fluid is a silicone oil. The modules are standardised and are delivered completely mounted to the installation site. Such an ORC-module is shown in Fig. 3.

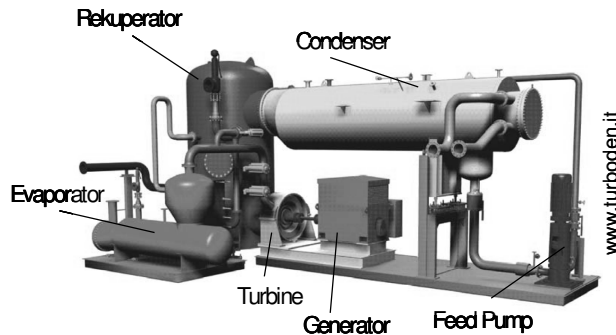


Fig. 3 Turboden ORC Module

The temperature of geothermal or waste heat is much lower, mostly in a range up to 150 °C. For this purposes mostly hydrocarbons or fluorocarbons are used as working fluids. For this purposes fewer projects have been realized.

The challenge in the project RO-Solar-Rankine was not only to handle a low temperature level, but also to design an ORC with a power output of around 10 kW_{mech}. For this purpose a scroll type expander was used instead of a turbine as expansion machine. The scroll type expander is a positive displacement machine with a built in pressure ratio.

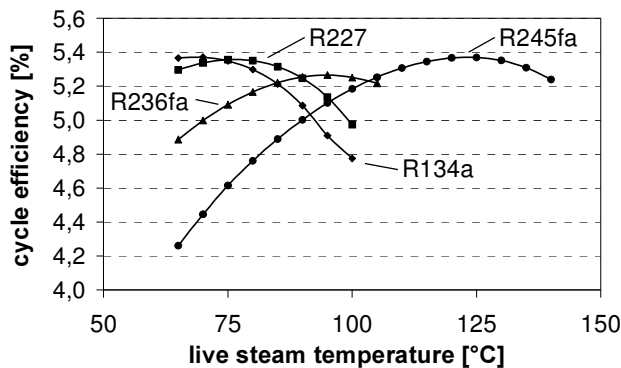


Fig. 4 Cycle efficiencies of different working fluids

The cycle efficiencies of different working fluids are shown in Fig. 4. Rising temperature in the evaporator causes rising live steam pressure. In ordinary turbines would this lead to rising power output and rising efficiency. Due to the built in pressure ratio of the scroll type expander higher live steam pressures lead to higher condenser pressures. This causes the specific efficiency-maxima of the different working fluids. For the project RO-Solar-Rankine R134a was chosen due to the efficiency maximum at the lowest possible temperature.

As conclusion it can be said, that the ORC is a proven technology for power production from low temperature heat down to 150 °C in a power range of 400 to 1500 kW. For lower temperatures and lower power output designated low temperature working fluids and especially suitable expansion machines have to be chosen to allow efficient operation.